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Simulation of photovoltaic installation connected to the grid with storage system

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Abstract

In the present paper, a new approach for the management of energy resources in a research laboratory is proposed and evaluated. A simulation study for the photovoltaic (PV) installation was conducted under the Tunisian-Italian cooperation project DE.DU.ENER.T, using renewable energy and economic criteria. The aim of the study is to improve the energy efficiency in order to minimize the electricity cost consumed in the laboratory. A Hybrid Renewable Energy System consisting of a photovoltaic field of 12KWc was installed to reduce the exorbitant bills, due to intensive energy equipment such as drying ovens and workstations, using sustainable, green and clean sources. In addition, a sizing theoretical study of the PV system was primarily realized in order to evaluate, in the first hand, the compatibility between different equipment and to compare, in the second hand, with results given by two software SMA Sunny Design and PV*SOL. We designed and managed these systems optimally to promote the self-consumption of the electric energy in the LPT Research laboratory building. The focus would be on the use of the PV system by evaluating the impacts of electricity generation using renewable energy levied on electricity grid (energy injection and extraction) and the economies that can be achieved during operating hours. Results of PV-SYST study obtained by the simulation of our installation will be discussed.

Peer-review under responsibility of the scientific committee of ICOME 2015 and ICOME 2016.

Keywords: Heat Transfer, Hybrid Energy System, Renewable Energy, Photovoltaic panel, Simulation

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Introduction

Hybrid Energy System (HES) is an electric energy system, which is made up of a single or many electric sources. These sources could be renewable, traditional, or mixed and work in connected or off-grid [1-3]. If the HES system contains only renewable energy sources it will be named "a Hybrid Renewable Energy System (HRES)" such as the photovoltaic system, the wind turbine. HRES can address emissions, reliability, efficiency, and economical limitations of single renewable energy source [3].The HRES systems are becoming famous for standalone power generation in the non-isolated and isolated area due to the growing, the improvement and efficiency in renewable energy technologies [4]. Actually, they have huge potential from an environmental point of view as they can reduce the gas emissions especially CO2 and limit pollutants emissions due to the not consumption of fuel or natural gas. Financially, The cost of solar and wind energy can be competitive comparing to the classical grid installation. The cost of these systems predictable and not influenced by fuel price and they can be easily installed and deployed for other utilizations [5-8]. Various hybrid renewable energy systems have been already deployed in different countries. It has been reported that it significantly reduce buildings energy consumption as the latter accounts for 40% of the overall energy consumption worldwide and correspondingly are responsible for carbon emissions. Efforts have been made to reduce CO2 emissions focusing on green energies. Studies for this purpose have explored the performance analysis of demonstration systems, the development of more efficient and innovative photovoltaic (PV) panel and innovative batteries and the storages systems [7]. This work will focus only on the study and the sizing of the PV installation for the DE.DU.ENER.T Project [8].

Nomenclature

Symbol	Description	Unit
$U_{mppt,max}$	Maximum input Dc voltage to the inverter	V
$U_{mppt,min}$	Minimum input Dc voltage to the inverter	V
U_{mpp}	Maximum voltage of the PV panel	V
U	DC Voltage drop	V
I, I_{Mpp}	Maximum current of the panel	A
L	Cable length	m
u	AC Voltage drop	V
b	Coefficient	No unit
s	Cable section	mm^2
$cos\varphi$	Power factor	No unit
λ	Linear reactance	Ω/m
I_b	Maximum output current of the inverter	A
Δu	Relative voltage drop	V
U_0	Nominal voltage	V
ΔV	Voltage difference	V
βV_{0C}	Temperature coefficient	%/°C
V_{string}	String voltage	V
ΔT	Temperature difference	°C
V_{max}	Maximum input voltage to the inverter	V
$I_{string\ input}$	Maximum input current per string	A
ρ, ρ_1	Resistivity of the conductive wire	$\Omega.mm^2/m$

2. Tunisian prototype

1.1. Description of the prototype

The Tunisian prototype of the DE.DU.ENER.T was installed near the Laboratory of Thermal Processes, a part of the Research and Technology Centre of Energy CRTEn, to reduce the energy consumption consumed from the grid by the laboratory, and composed of 12KW of photovoltaic field and a 1KW of wind turbine.

(a) (b)

Fig. 1. the laboratory LPT (a) and the platform of our installation (b).

1.1. Work methodology and laboratory equipment

Because of the unavailability of an electrical consumption meter dedicated to the laboratory (LPT), we made an estimation of the energy consumption of the latter. To make this estimation, we conducted census of electrical equipment used by one local of this laboratory.

This local contain three type of Equipment:

- Laboratory equipment such as drying oven, desiccator and precision balance,
- Workstations and laser printer,
- Lighting equipment

Then we extrapolated this consumption for the remainder of locals and offices for this laboratory. Finally, we have refined our extrapolation by an error margin of 10%.

After identifying the different equipment of the laboratory, we tried to identify the optimal operating mode (number of unit, operating hours...) and identified the different electrical characteristics (current, voltage, power...) for each appliance to determine the real power consumption in this laboratory and the higher energy consuming equipment.

The power consumed by each equipment is calculated as follows:

$$\text{Total Power} = \text{Unit power x Quantity}$$
$$\text{Daily Power} = \text{Total Power x Hours Operating / day}$$
$$\text{Mounthly Power} = \text{Daily Power x Number of day per mounth}$$
$$\text{Annualy Power} = \text{Mounthly Power x Number of mounth}$$

The development of control strategies asks for a computationally efficient energy model of a building under study. Consequently, after determining these powers, the photovoltaic power to install is determined by the following expression:

$$\text{PV Power} = \sum \text{Annualy Power} \Big/ \text{Basic Consumption} \quad (1)$$

According to the previous figures, we can conclude that there are two types of energy consuming equipment that are drying oven and the workstations [9].

1.1. Theoretical sizing of the equipment

- Photovoltaic Panel

We have chosen to install Yingli Solar monocrystalline photovoltaic panels of 250 Wc, tinted in black because in this case it becomes more selective and we will have a maximum yield of 15.3%.

Table 1. Electrical characteristics of PV panel

Characteristics	*Units*	*STC Conditions*	*NOCT Conditions*
Maximum Power	W	250	181.6
Voltage at Pmax	V	28.9	26.4
Current at Pmax	A	8.66	6.91
Open circuit voltage	V	37.6	34.8
Short circuit cuurent	A	9.29	7.50

Table 2. Thermal characteristics of PV panel

Characteristics	*Symbol*	*Units*	*Value*
Nominal Temperature of cell		°C	46 +/- 2
Temperature coefficient for Pmax	γ	%/°C	-0.42
Temperature coefficient for Voc	β_{Voc}	%/°C	-0.31
Temperature coefficient for Isc	α_{Isc}	%/°C	0.04
Temperature coefficient for Vmpp	β_{Vmpp}	**%/°C**	-0.41

For our installation of 12 Kw with a type of exposure and incline of 36°, using a single inverter is sufficient. But, for larger installation the use of multiple inverters can reduce the risk of outages. The selected inverter is a Sunny Tripower 12000 TL-20 whose technical characteristics are presented in [9]

We must make sure that voltage delivered by the PV field belongs to the MPPT voltage range of the inverter. If it does not, the installation may have a power loss. This MPPT voltage range will also have an impact on the number of PV panels in string [9-11].

The following equations are used to determine the minimum and maximum number of PV panels in string:

$$\text{Maximum number of panels} = E\left(\frac{\text{Umppt, max}}{\text{Umpp*1,15}}\right) \quad (2)$$

$$\text{Minimum number of panels} = E\left(\frac{Umppt, \min}{Umpp * 0,95}\right) \quad (3)$$

The theoretical calculation has given us a minimum number of 16 panels and a maximum number of 24 panels, and we will connect to the A input of the inverter 32 panels according to 2 strings and to the B input 16 panels into a single string. The sizing of an inverter per string is based on three criteria: power compatibility, Maximum voltage compatibility, current compatibility. The power of the inverter must be significantly different to the power of the field that is why this power must be undervalued approximately by 5-15% and be increased by 10-20% relatively to the maximum power of the field [12-13].

$$0.85 < \frac{\text{Maximum power of inverter}}{\text{Field power}} < 1.2 \quad (4)$$

An inverter is characterized by a maximum input voltage equal to 1000V and if the voltage delivered by the PV panels exceeds this value the inverter may be damaged. The following equations are used to verify this compatibility [12]:

$$\Delta V = \beta V_{OC} * V_{string} * \Delta T \quad (5)$$

$$V_{max} = V_{string} + \Delta V \quad (6)$$

An inverter is characterized by a maximum input current. So when the DC input current exceeds the maximum current admissible by the inverter it continues to operate, but provides to the grid the corresponding power at peak current.

This compatibility is verified by the following expression:

$$I_{string\ input} = \text{Number of string} * I_{Mpp} \quad (7)$$

To properly sizing our facility, we must have a voltage drop not exceeding than 3% of the AC or DC part. For this, we must calculate these two voltage drops according to NF C 15-100 and NF C 14-100 norms by these following expressions [13-14].

$$U = \left(\frac{I * \rho * L}{S} \right) \quad (8)$$

$$u = b * \left(\rho_1 \frac{L}{S} \cos\cos\varphi + \lambda L \sin\sin\varphi \right) * I_b$$

$$\Delta u = \left(\frac{U}{U_0} \right) * 100 \quad (9)$$

3. Results

1.2. Simulation by SMA Sunny Design and PV SOL software

In this part, we realized a simple simulation for the photovoltaic installation by the SMA Sunny Design [15], which is photovoltaic software for SMA inverters like our inverter. The important object for this sizing is to compare the results for the power, voltage and the current compatibility, which are found theoretically with those found by this software. The compatibility for the voltage range and the input current between the out photovoltaic field and the input of the inverter has been illustrated previously [9,14]. The following figure presents the consumption profile for our system by using some battery to storage some energy for lighting at night, and the effect of this installation to reduce the quantity of electricity purchased from the grid. We know that the energy consumed by our laboratory per year is equal 49505 KWh and with results of this profile of self-consumption, we can conclude that the self-sufficiency quota is equal 32.2% (in percentage of PV Energy) and the self-consumption quota is equal 82.4% (in percentage of Energy Consumption per year).

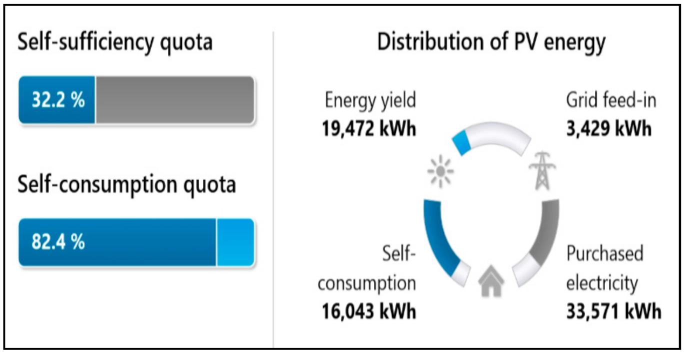
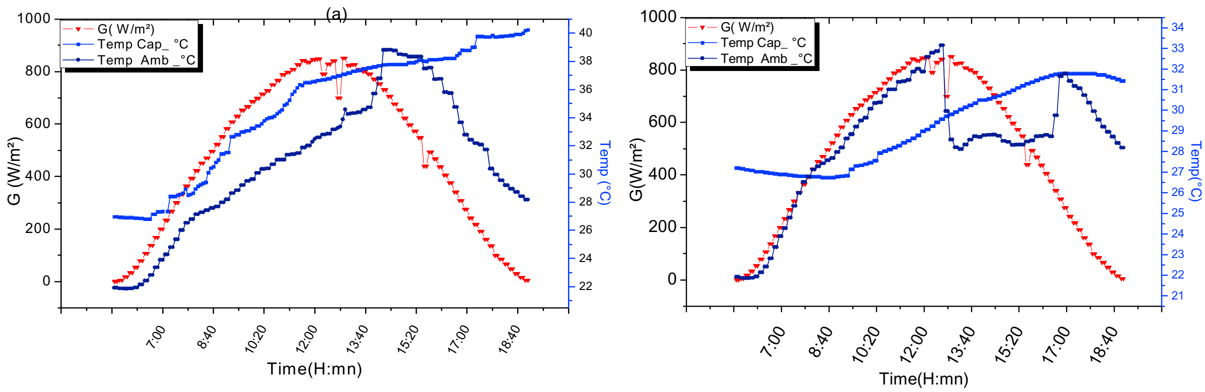


Fig. 2. self Consumption profile.

In this part we realized a simulation for our photovoltaic installation by the PV*SOL software to have some idea about the efficiency for this system and to compare some results with the others results given by SMA Sunny Design software.

1.3. Temperature profiles

In the following figures, we present the profile of the panel temperatures using the meteorological database of 2016 for Techno Park site of Borj Cedriya (south of Tunis City) that allows to accurate data for solar irradiation, wind, temperature and more weather parameters. We noted that these profiles are proportional and that the peak temperature appears in the summer with a maximum of outside temperature equal to 38°C and a maximum of PV panel temperature equal to 40°C.



(*a*) (*b*)

Fig. 3. Temporal evolution of solar irradiation (G), ambiant temperature (Temp-Amb) and PV Panel temperature (Temp-Cap) for a typical day of July 2016 (*a*) and May 2016 (*b*).

1.4. Performance Ratio (PR)

The performance ratio (PR) is indicated in percentage and is the ratio between the real and the theoretical yield of the photovoltaic system. If the value of this ratio approaches of 100%, we consider that this photovoltaic system has an efficient operation. However, it is not possible to reach the value of 100% in practice because the operation of the photovoltaic system always generates inevitable losses such as the thermal and conduction losses. The performance ratio is calculated as follows [14]:

$$\text{Performance Ratio} = \text{Real yield} \Big/ \text{Theorical yield} \tag{12}$$

In the following figure, we present the profile of this performance ratio. We noted that our installation is effective because it have a higher performance ratio (more than 80%) and we deduct that this value is fluctuating because of some conditions such as panel temperature, shading, solar irradiation and the energy losses.

1.5. Forecast Production with consumption

In the following figure 5, we present the quantity of the energy produced by the PV installation, the energy consumed from the grid and a little quantity of energy stored by using batteries. We noted that by summing each monthly power produced or purchased we find a very similar value to that found previously by using the SMA Sunny Design software [14]. This small variation is due to the difference between the values of each weather databases [15].

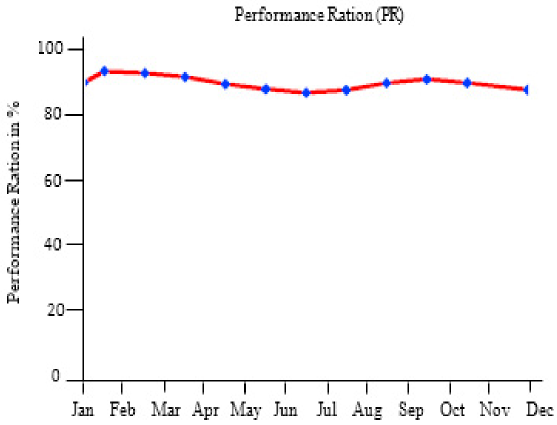


Fig. 4. Performance ratio

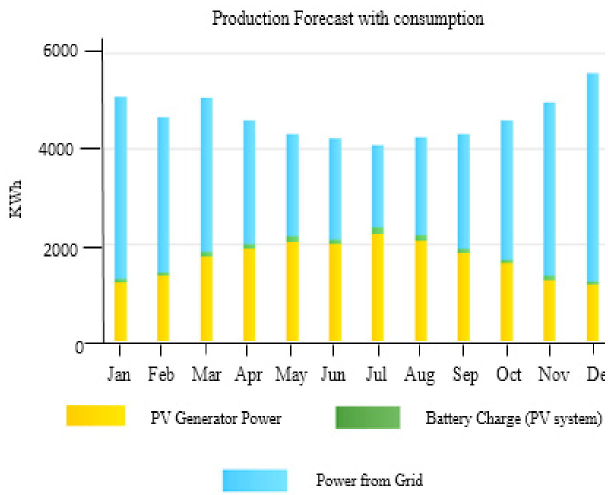


Fig. 5. Production forcast with consumption

4. Conclusion

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First, it shows the approach used to realize our theoretical sizing study. Next, we performed simulations by means of professional software for photovoltaic installations in order to have an idea about the profitability of our system and to compare the results found. Finally, we conclude that the results are very similar and they show the efficiency of our system, then this installation will allow us to reduce the cost of electricity purchased from the grid.

Recent results of the simulation study realized by some industrial software such as PV*Syst and PV*SOL indicate that the hybrid electric system could provide about 39% of the total consumption of the electricity for our laboratory. Our solar devices allow the order of 4500 KWh energy saving and CO2 emissions reduction of about 2600 Kg per year.

After the connection of this hybrid system to the electricity distribution grid, some measurements and data will be extracted to use it for the Capitalization and Monitoring study.

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